Could Zinc Whiskers Be Impacting Your Electronic Systems? Raise Your Awareness

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During the past several decades electrical short circuits induced by "Zinc Whiskers" have been cited as the root cause of failure for various electronic systems (e.g., apnea monitors[1], telecom switches[2]). These tiny filaments of zinc that may grow from some zinc-coated items (especially those coated by electroplating processes) have the potential to induce electrical shorts in exposed circuitry. Through this article, the authors describe a particular failure scenario attributed to zinc whiskers that has affected many facilities (including some NASA facilities) that utilized zinc-coated raised "access" floor tiles and support structures. Zinc whiskers that may be growing beneath your raised floor have the potential to wreak havoc on electronic systems operating above the floor.

Figure 1: Zinc whiskers found growing from bottom of an access floor tile (~100x). Many have lengths on the order of 1 mm or more.

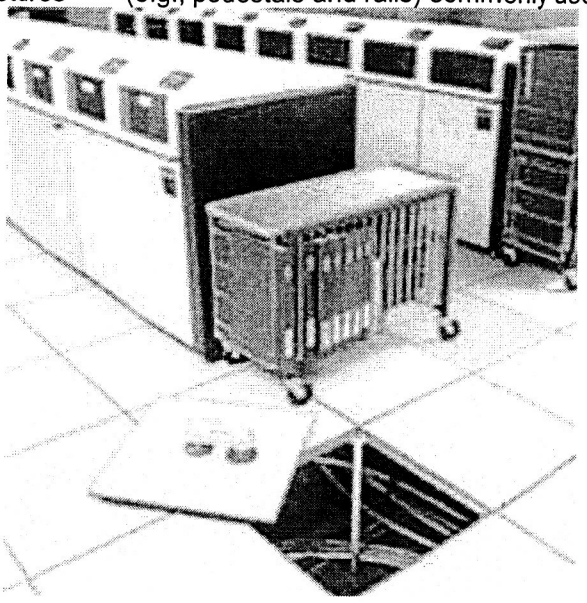
What are Zinc Whiskers?

Zinc whiskers (Fig. 1) are tiny conductive filaments of zinc typically less than a few millimeters (mm) long and only a few thousandths of a millimeter in diameter. They may grow from some metal surfaces (e.g., steel) that have been coated with zinc (especially by electroplating processes) for corrosion protection. The growth process consists of an unpredictable incubation period lasting months or perhaps even years followed by a period of growth at rates as high as 1 mm/year. Due to their miniscule diameter, zinc whiskers can be extremely difficult to see without magnification and/or proper illumination techniques.

The precise mechanism of growth remains unknown despite the fact that zinc whiskers were first identified in the 1940's. In the decades since, there has been very limited research aimed specifically at the zinc whisker phenomenon. However, during this same time period, there have been over 100 reports/studies written about the phenomenon of tin whisker formation, which most authors agree seems to be a closely related process. Despite this extensive research, identification of the precise growth mechanism(s) for tin whiskers has also remained elusive. The NASA Goddard Tin and Other Metal Whisker WWW Site [3] contains an extensive listing of available reference materials on this subject matter (http://nepp.nasa.gov/whisker).

Where do Zinc Whiskers Grow?

Through the years zinc whiskers have been observed growing on a variety of zinc-plated items including both electrical components (e.g., electromagnetic relays) and mechanical hardware (e.g., nuts, bolts, washers, equipment racks, housings and rails). In recent years, however, the most frequently reported source for zinc whiskers appears to be the zinc-plated UNDERSIDE of some raised "access" floor tiles and their support structures [4 - 14] (e.g., pedestals and rails) commonly used in computer data centers (Fig. 2).



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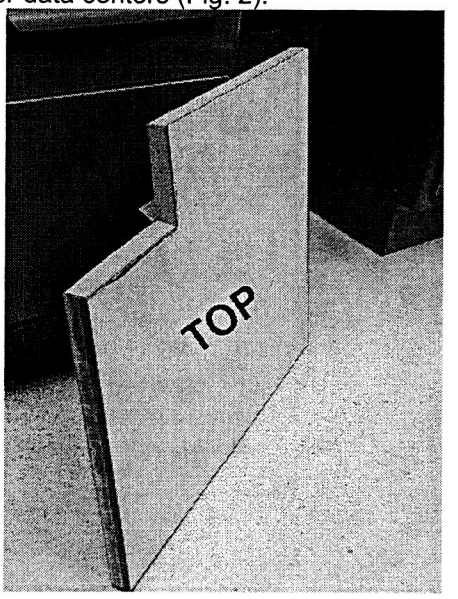

2b)

Figure 2: A Typical Raised "Access" Floor System.
a) A data center floor system with one tile lifted illustrating that the floor is raised and supported by pedestals and stringers to facilitate under-floor cable routing. The sub-floor space is also used as an air plenum.
b) Top/side view of one type of access floor tile. This tile has been cut revealing a vinyl top surface attached to a 1-inch thick wood fiber core onto which a thin sheet of zinc-electroplated steel has been glued to the bottom and sides.

Zinc Whiskers Growing on Raised "Access" Floor Structures

Raised floor tiles, pedestals and stringers are often constructed of steel to provide good structural integrity. A thin zinc coating applied either by electroplating or hot dip galvanization (HDG) is commonly used to protect the steel from corrosion. It is this thin zinc film that is at risk of forming zinc whiskers over time especially (though not exclusively) for those films applied by electroplating processes. Figure 2b shows one type of access floor tile that has been observed to have zinc whiskers. Figure 3 shows the underside of this tile which when examined using high intensity light shined parallel to the surface reveals what appears to be fuzzy, dust-like formations. Closer examination reveals that the dust-like appearance is actually millions of zinc whiskers shown in Figure 1.

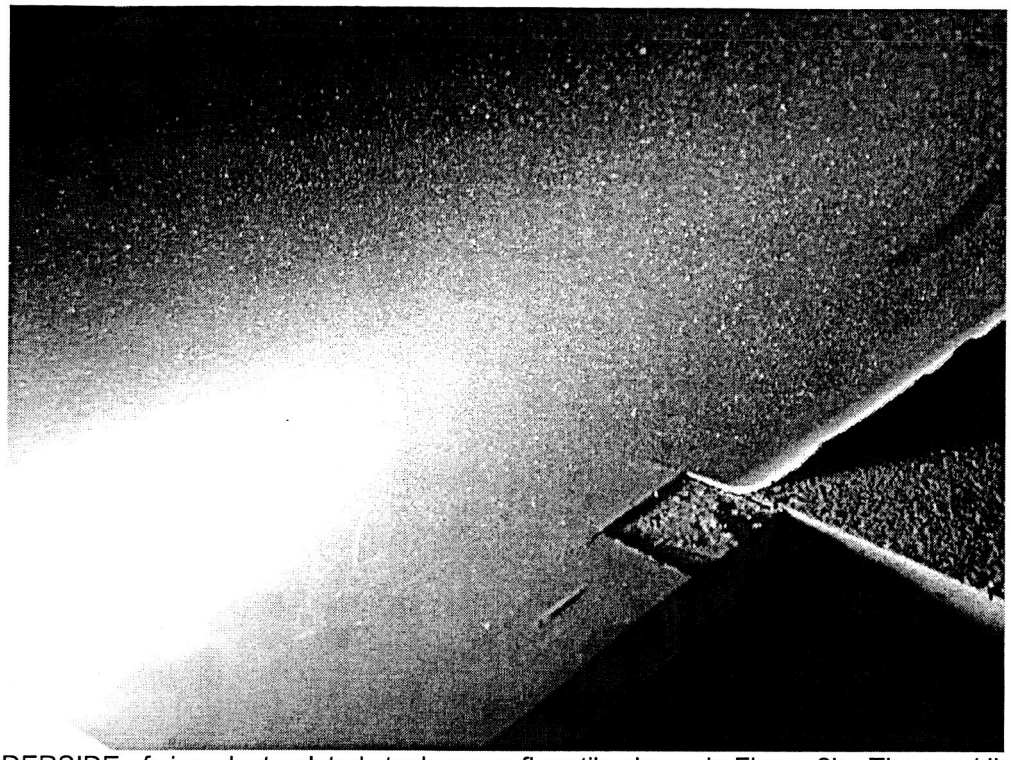

Figure 3: UNDERSIDE of zinc-electroplated steel access floor tile shown in Figure 2b. The sparkling "dust-like" appearance on surface is actually millions of zinc whiskers (shown magnified in Figure 1)

Electrical Hazards Caused by Zinc Whiskers

During a recent one-month period a NASA data center experienced at least 18 catastrophic power supply failures in newly installed mass memory storage devices. The ensuing failure investigation determined the most probable cause of failure to be electrical short circuits induced by zinc whiskers that bridged exposed conductors within the power supplies. The source of the zinc whiskers was identified to be the zinc-electroplated steel UNDERSIDE of the raised "access" floor tiles and possibly the zinc-electroplated floor support structures (pedestals and stringers) used in this facility. Whisker densities on the order of millions per single floor tile (area = 4 square feet) have been observed. At the time the equipment failures were experienced, the floor tiles in the affected NASA data center were approximately 10 years old.

The review further determined that the zinc whiskers were most likely dislodged from the floor structures during the floor handling/bumping activities involved in the new equipment installation. Subsequently, loose zinc whiskers became entrained in the data center airflow with some ultimately being deposited inside the affected equipment where they were able to induce the observed electrical short circuits. Zinc whiskers growing on the underside of raised floor structures may seem to be a long distance from electronic systems that are operating above the floor. However, experience has demonstrated that floor-bumping activities such as lifting, sliding and reinstallation of access floor tiles and pulling of electrical cable in the sub-floor space can dislodge whiskers from their point of origin. Because of their small size and weight, zinc whiskers are easily redistributed throughout the facility via the forced air-cooling. The sub-floor space in raised floor facilities is commonly pressurized with chilled air to provide efficient cooling. Perforated floor tiles and air vents provide channels through which the cool air and along with it, zinc whiskers, can be blown into the above floor space. Ultimately, many whiskers may be drawn inside of electronic hardware through vents and fans on the equipment. Once inside the equipment zinc whiskers may cause a variety of electrical failures ranging from intermittent to permanent short circuits. Whisker debris may also become a physical impediment to moving parts or obscure optical surfaces and sensors within some equipment (e.g., disk or tape drives). Figure 4 shows a graphical representation of the zinc whisker failure mechanism as it pertains to raised floor facilities.

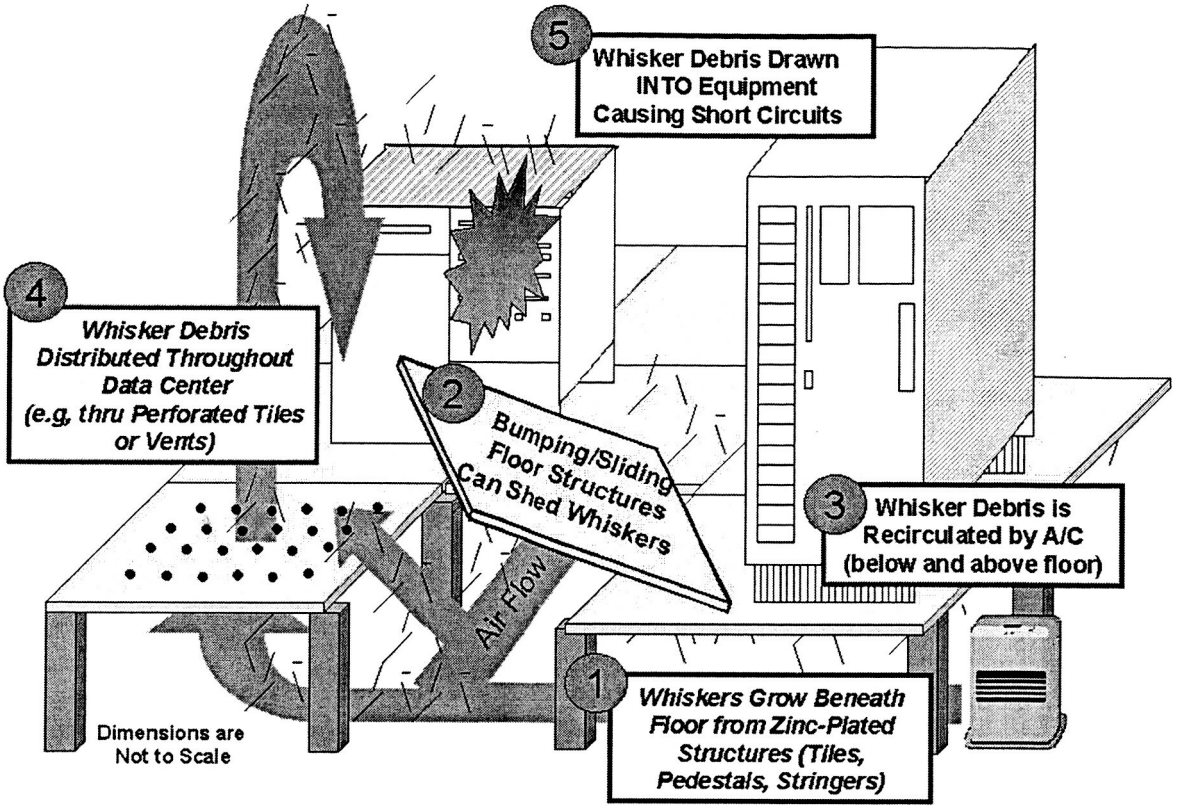

Figure 4. Graphic representation of the mechanism by which zinc whiskers growing on raised floor tiles, pedestals or rails can be distributed throughout a data center

What about potential health hazards?

During our investigation into this phenomenon, concerns were raised about potential health hazards from exposure to zinc whiskers. NASA is still reviewing this issue but our initial research has not identified any specific studies or published guidance. There is considerable literature discussing the toxicity of zinc in other forms, particularly zinc oxide in the form of granules, powder, fumes and dust. In these forms zinc seems generally benign when inhaled or swallowed except in very high concentrations. Inhalation of zinc fumes can have more serious effects. There are various informal reports on zinc whiskers that suggest there are no health implications from exposure; however, these reports lack cited references from medical or occupational health professionals. Research suggests that the shape of airborne fibers may be an important factor regarding the potential pathologic effects on the lung, specifically a length to width ratio of 100 to 1 or greater. Zinc whiskers commonly exceed this ratio. It is recommended that organizations that suspect their facilities may have zinc whisker formation should consult with appropriate occupational health and medical professionals for guidance on appropriate measures to implement (if any) for personnel safety.

Why the Renewed Interest in Zinc Whiskers Today?

A review performed by engineers supporting NASA Goddard Space Flight Center has determined that electronic equipment failures from zinc whisker debris in raised floor facilities have been experienced by numerous domestic and international organizations during the past several years [4 - 15]. Several factors appear to be contributing to the apparent increase in reported failures including:

1. *Continuous Miniaturization of Electronic Components*
   Technological advances have led to more densely packed circuitry and tighter spacing between conductors. As a result, smaller conductive particles can now cause short circuits.
2. *Reduction in Circuit Voltages and Currents*
   Many newer electronic systems operate at lower voltages and currents. Energy available from these components may not be sufficient to melt a zinc whisker thus resulting in increased risk for permanent shorts.
3. *Age of Existing Floor Structures*
   Many facilities now have zinc-plated floor structures that are 10, 20, 30 years old or more. Thus where zinc-

plated floor structures are in use, whiskers have had time to grow to lengths capable of bridging exposed conductor spacings in most modern electronic systems.

4. *Increased Maintenance/Upgrade Activity in Raised Floor Facilities.*
   Any activity in the raised floor facility that involves handling or impacts to floor structures has the potential to dislodge zinc whiskers if the structures are already infested with these growths. In today's high technology environment it is more commonplace for computing facilities to undergo regular maintenance activity to perform tasks such as add/remove hardware, reposition/reconfigure the equipment, or general troubleshooting.

What are the Commonly Reported Attributes of a Zinc Whisker Attack?

A review of the published literature and discussions with other affected organizations have revealed the following common attributes to most zinc whisker failure experiences in data centers:

1. Most users had never heard of zinc whiskers until the problem affected their systems.
2. Inexplicable system failures began concurrent with (or within weeks of) maintenance activities requiring handling/impacts to floor tiles. Failures of power supplies are most obvious because of the impact they have on system operation. However, failure of other electronic systems (logic cards, motherboards, memory devices, etc.) may also be occurring with less obvious but potentially serious effects.
3. Newer equipment seems to be more susceptible to failure than older equipment.
4. Equipment located adjacent to floor vents seems more susceptible to failure.
5. Users may not thoroughly investigate periodic intermittent system failures unless/until permanent hardware failures begin to occur or substantial system "down-time" occurs. Invoking service contracts and warranties sometimes means that problem investigation stops as soon as replacement equipment is supplied.
6. Failure investigations (and corrective action attempts) frequently consider electrical power spikes and/or inadequate cooling before identifying zinc whiskers as a suspect. Techniques for investigating these other kinds of problems may involve significant handling of floor tiles and can actually generate additional whisker-induced problems.

Unfortunately, this zinc whisker failure mechanism appears to be quite widespread while awareness by facility or data center management personnel appears to be rather limited. NASA Goddard hopes that this report will help other organizations to identify a potentially serious hazard BEFORE problems are experienced.

How Can One Determine if their Facility is at Risk?

Zinc whisker identification, detection and mitigation should be taken very seriously. Improper procedures have the potential to produce additional hazards and failures. Rather than attempt to conduct these activities alone, organizations who suspect they may currently be experiencing or be prone to future zinc whisker related problems are strongly advised to seek expert advice from (but not limited to) the following types of professional organizations:

1. Supplier of Electronic Hardware in the Facility
2. Original Supplier of Floor Structures
3. Professional Data Center Cleaning or Disaster Recovery Companies Familiar with Zinc Whisker Abatement
4. Occupational Health and Safety and/or Medical Professionals

Data center managers are encouraged to review equipment maintenance records as well as the equipment self-diagnostic fault logs for abnormally high failure rates. Such trends, especially if concurrent with floor handling activities, may be an indicator of an active zinc whisker problem.

What Remediation Approaches are Available?

The affected NASA data center has implemented some short-term corrective actions and is currently evaluating long-term solutions to their zinc whisker problem. Among the short-term corrective actions being implemented are:

1. Replacement power supplies have had exposed electronic circuitry coated with a protective insulating compound by the original equipment manufacturer. This coating will minimize (not necessarily prevent) the risk of future power supply short circuits from zinc whisker debris.
2. Activities within the data center that require significant handling of floor tiles have been reduced until long-term mitigation strategies have been evaluated

For long-term solutions, the NASA data center is evaluating proposals from industry professionals that include, but are not limited to:

1. Carefully planned/controlled removal of all affected and/or suspicious tiles and/or support structures while protecting both equipment and personnel,

2. Thorough cleaning of the data center environment (e.g., HEPA filter vacuuming) to remove as much whisker debris as possible
3. Replacement of floor structures with systems that are not prone to zinc whisker formation. Alternatives being considered include all-aluminum structures or steel structures that utilize conductive epoxy powder coatings or paints instead of zinc for corrosion protection.

CAUTION: Protective coatings of zinc over steel are commonly applied by one of two general coating processes: electroplating or hot dip galvanization (HDG). Many cases of zinc whiskers growing on "electroplated" zinc structures (including raised floor structures) have been reported. Coatings of zinc applied by HDG processes are frequently reported to be immune to the whisker phenomenon. However, we have recently seen one report citing evidence of zinc whiskers (some > 0.3 mm long) growing on a floor tile and support structures that were advertised to be HDG-coated.[15] We recommend caution when using **any** zinc coating in applications where zinc whiskers may pose a hazard.

NOTE: Simple washing of whisker-infested materials is not considered to be an effective long-term remedy. Whiskers can grow back. In addition, the effectiveness of coating materials applied over whisker-prone surfaces should be evaluated prior to use because whiskers may be able to grow through some conformal coatings depending on the material's properties and thickness.

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